Contributions Toward an Integrative, Process-Based Model of Stratigraphy Formation

Lincoln F. Pratson
Division of Earth and Ocean Sciences
Duke University
Durham, NC 27708-0230
phone: (919) 681-8077 fax: (919) 684-5833 e-mail: lincoln.pratson@duke.edu

Award No.: N00014-99-0044
http://www.geo.duke.edu/faculty/pratson.htm

LONG-TERM GOALS

My long-term goals are to improve our understanding of the physical evolution of the continental shelf and slope, and to enhance our ability to extract stratigraphic information from geophysical data of these regions.

OBJECTIVES

The specific objectives of this project are to:

(1) Aid the development of the integrative stratigraphic modeling system SEQUENCE (Steckler, 1999) by:

  a) helping create a component model for the long-term evolution of shelf strata, and

  b) creating a component model for the long-term evolution of slope strata.

(2) Develop a model for generating synthetic seismograms of stratigraphic simulations produced by SEQUENCE and by SEDFLUX (Syvitski et al., 1999), the second integrative stratigraphic modeling system being developed for ONR.

(3) Continue work on modeling of unconfined submarine debris flows and validate this work against experimental flows.

APPROACH

SEQUENCE is being designed to rapidly simulate the first-order evolution of continental margin morphology over long geologic time periods. To meet this requirement, the shelf and slope component models for SEQUENCE are 1-D, Eulerian, finite-difference models that produce 2-D, dip-line simulations of shelf and slope evolution. Both are relatively fast and encompass the physiographic provinces in their entirety, using annual to multi-year time steps, and distance steps of tens of meters. The shelf model simulates the formation of shelf strata under the combined effects of sediment supply, waves, and a long-term, net-offshore current. The slope model simulates episodic failure and/or the bypassing of sediments to the deep sea.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE
Contributions Toward an Integrative, Process-Based Model of Stratigraphy Formation

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Division of Earth and Ocean Sciences,,Duke University,,Durham,,NC, 27708

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
My long-term goals are to improve our understanding of the physical evolution of the continental shelf and slope, and to enhance our ability to extract stratigraphic information from geophysical data of these regions.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

The modeling of synthetic seismograms from strata generated by SEQUENCE and SEDFLUX requires two separate models. The first model generates the physical properties needed to produce synthetic seismograms, principally bulk and shear moduli. The second model uses these properties to simulate the theoretical response of the computer-generated strata to seismic energy, including its attenuation.

Submarine debris flows and the deposits they produce are being modeled in three dimensions using a 2-D, layer-averaged, numerical model of a Bingham fluid. The model is to be validated against unconfined experimental debris flows, the heights and velocities of which have been well documented.

The shelf and slope modeling is being done in collaboration with Drs. Pat Wiberg (UVA), John Swenson (UMinn-Duluth), Chris Paola and Gary Parker (UMinn-Minneapolis). The seismic modeling is being done with Dr. Anastasia Stroujkova (Duke/UConn). And the debris flow modeling is being done with Drs. Jim Buttles (MIT) and Gary Parker (UMinn-Minneapolis).

WORK COMPLETED

The shelf model continues to be refined, but a working version is up and running. In the model, sediments introduced at the coast are kept in suspension by wave energy and gradually moved basinward until water depths become deep enough that the wave energy is too low to prevent long-term sediment accumulation.

The slope model is also up and running. In this model, sediment that escapes the shelf accumulates on the slope until the slope reaches a critical angle. At this point, the sediments either bypass the slope or the slope fails depending on the user's preference. The bypassed or remobilized sediments are then transferred to the deep sea.

In order to test the performance of the shelf and slope models, the two have been linked with component models for the coastal plain and the deep sea. The coastal plain model, which uses diffusion to approximate fluvial deposition and erosion (Paola et al., 1992), provides the sediment input to the shelf model. The deep-sea model uses a diffusion equation derived from the conservation equations for a turbidity current (Parker et al., 1986) to distribute the sediment received from the slope model across an adjoining continental rise.

The physical property model needed for generating synthetic seismograms is complete (Herrick, 2001; Stroujkova et al., in prep.). It can be used to simulate bulk and shear moduli not only for computer simulations of strata, but also for experimental strata created in the laboratory. The model can accept a range of properties as input, but requires only clay content to predict porosity, bulk density, elastic moduli, and compressional and shear velocities. The model has been validated against well logs from ODP boreholes on the Amazon Fan.

A 1-D poro-elastic model of seismic wave propagation is also complete. The model has been exercised in simulating synthetic seismograms of experimental strata using a range of source frequencies (e.g., 100 - 2000 Hz) and source signatures (e.g., chirp, airgun and watergun) (Pratson et al., 2001) (Fig. 1).

Finally, the unconfined debris flow experiments needed to validate the 2-D, layer-averaged debris flow model have been completed.

RESULTS

- The shelf model predicts that continental shelves should evolve to a relatively flat gradient, the dip of which, if any, is controlled by the dissipation of wave energy across the shelf.

- The slope model predicts that repeated slope failure creates an abrupt shelf break, while slope bypassing fosters and preserves a more gradual rollover across the shelf edge.

- Using clay content as the only input, the physical property model can predict the porosity, bulk density and velocity of sediments from the Amazon Fan to within a RMS error of < 10%.

- The seismic model successfully reproduces the greater attenuation of seismic energy by sandy sediments versus those that are clay rich over seismic frequencies commonly used to image shelf and slope strata (Fig. 1).

IMPACT/APPLICATIONS

- The prediction that continental shelves should evolve to relatively flat surfaces is due to the shelf model's simplicity, but the result raises the interesting question of what creates and controls the slope of the shelf (e.g., modern marine processes or past subaerial processes during sea level lowstands like rivers?). This is a question that Dr. Pat Wiberg and others are pursuing.

- Based on observations, shelf-break abruptness appears in general to be inversely correlated with sediment supply. Abrupt shelf-breaks are characteristic of stationary continental margins with moderate to low sediment supply, while rounded shelf-breaks are common along prograding margins with high sediment supply (O'Grady et al., 2000).

- While clay content can be used to predict seismically important physical properties of marine sediments, it itself is a property that is poorly measured, if it is measured at all.

- With some pre-existing knowledge of sediment type, it appears that a 1-D poro-elastic model can be used to predict what seismic source would yield the best images in a given area. Conversely, under certain conditions (e.g., gas-free sediments), the model may allow for gross predictions about sediment type from the attenuation of a given seismic source.

TRANSITIONS

The linked coastal-plain, shelf, slope and rise models have been provided to Dr. Mike Steckler (L-DEO). He has already incorporated them into SEQUENCE, and he has used them to produce example simulations of margin evolution (Steckler et al., 2001). Similarly, the physical property and seismic models have been provided to Dr. James Syvitski. He will be using them in the future to generate synthetic seismograms of strata simulations produced by SEDFLUX. Dr. Jim Buttles has been working with the results from the debris flow experiments in testing the debris flow model. And the experiment results have also been used by a Duke undergraduate who analyzed them for his honor thesis this past spring (2001) (Henderson, 2001)

RELATED PROJECTS

I am continuing my work with Dr. Dave Cacchione on the relationship between the dynamics of internal waves and the gradients of the continental slopes (Cacchione et al., in 2001). We are now extending our analyses beyond the STRATAFORM study areas, and looking at the relationship on a global basis.

REFERENCES

Cacchione, D., L. Pratson, and A. Ogston, 2001. Internal waves and sedimentation on oceanic slopes: *AGU Chapman Conference on the Formation of Sedimentary Strata on Continental Margins*, Ponce, Puerto Rico, June 17-19, 2001.

Henderson, J-P., 2001. An analytical approach to debris flows: B.S. Honors Thesis, Duke University, 25 pp.

Herrick, D., 2001. A survey of existing velocity models using physical properties derived soley from clay content: Ph.D. Thesis, Duke University, 54 pp.

O'Grady, D., Syvitski, J., Pratson, L.F., and Sarg, J.F., 2000. Categorizing the morphologic variability of siliciclastic passive continental margins: *Geology*, v. 28, p. 207-210.

Paola, C., P.L. Heller, and C.L. Angevine, 1992. The large-scale dynamics of grain-size variation in alluvial basins, 1: Theory: *Basin Research*, v. 4, p. 73-90.

Parker, G., Y. Fukushima, and H.M. Pantin, 1986. Self-accelerating turbidity currents: *Journal of Fluid Mechanics*, v. 171, p. 145- 181.

Pratson, L., J. Buttles, J. Imran, G. Parker, P. Harff, H. Toniolo and J. Marr, in press. Numerical modeling of unconfined debris flows (abs): *Society of Engineering Science 37th Annual Technical Meeting*, Columbia, South Carolina.

Steckler, M.S., 1999. High resolution sequence stratigraphic modeling: 1. The interplay of sedimentation, erosion and subsidence. In: L. Whatney et al. (eds.), *Numerical Experiments in Stratigraphy: Recent Advances in Stratigraphic/Sedimentologic Computer Simulation*: SEPM Special Publication No. 62, p. 139-150.

Stroujkova, A., D. Herrick, and L. Pratson, in prep. Seismic velocity prediction using physical properties derived solely from clay content: to be submitted to *Geophysics*.

Syvitski, J.P.M., L. Pratson, and D. O'Grady, 1999. Stratigraphic predictions of continental margins for the Navy. In: L. Whatney et al. (eds.), *Numerical Experiments in Stratigraphy: Recent Advances in Stratigraphic/Sedimentologic Computer Simulation*: SEPM Special Publication No. 62, p. 219-236.

Pratson, L.F., A. Stroujkova, D. Herrick, and C. Paola, 2001. Seismic simulations of buried channels on a continental shelf: *AGU Chapman Conference on the Formation of Sedimentary Strata on Continental Margins*, Ponce, Puerto Rico, June 17-19, 2001.

FY01 PUBLICATIONS

Bahr, D., E. Hutton, J. Syvitski, and L. Pratson, 2001, Compaction from first principles: an analytical solution for approximating sediment porosity profiles: *Computers & Geosciences*, v. 27, p. 691-700.

Fryer, G.J., P. Watts, and L.F. Pratson, in press, The tsunami of 1 April 1946: a landslide in the upper forearc, in P. Watts, C.E. Synolakis, and J.-P. Bardet (eds), Prediction of Underwater Landslide Hazards, Rotterdam, *Balkema Publications*.

Mohrig, D., L. Pratson, and G. Parker, 2001, Connecting the transport processes of sediment-gravity flows to construction of the seafloor: SEPM Diamond Jubilee, Denver , Colorado, June 3-6.

Paola, C., J. Mullin, C. Ellis, T. Hickson, D.C. Mohrig, J.B. Swenson, G. Parker, P.L. Heller, L. Pratson, J. Syvitski, B. Sheets, and N. Strong, 2001, Experimental stratigraphy: *GSA Today*, v. 11, no. 7, p. 4-9.

Pratson, L.F., J. Imran, E. Hutton, G. Parker and J. Syvitski, in press. BANG1D: A one-dimensional Lagrangian model of subaqueous turbid clouds: *Computers & Geosciences*, v. 27, p. 701-716.

Pratson, L., J. Buttles, J. Imran, G. Parker, P. Harff, H. Toniolo and J. Marr, 2001. Numerical modeling of unconfined debris flows (abs): *Society of Engineering Science 37th Annual Technical Meeting*, Columbia, South Carolina, October 23-25, 2001.

Pratson, L.F., 2001, A perspective on what is known and not known about seafloor instability in the context of the evolution of continental margins: *Marine and Petroleum Geology*, v. 18, p. 499-501.

Pratson, L.F., J. Marr, and G. Parker, 2001, Experimental modeling of submarine debris flows: *American Association of Petroleum Geologists Annual Convention*, v. 10.

Pratson, L.F., A. Stroujkova, D. Herrick, and C. Paola, 2001. Seismic simulations of buried channels on a continental shelf: *AGU Chapman Conference on the Formation of Sedimentary Strata on Continental Margins*, Ponce, Puerto Rico, June 17-19, 2001.

Pratson, L., and Gouveia, W., in press. Seismic simulations of experimental strata: *AAPG Bulletin*.

Steckler, M.S., G. Parker, P. Wiberg, D. Swift, J. Swenson, C. Reed, L. Pratson, S. Parsons, C. Paola, A. Niedoroda, J. Locat, H. Lee, M. Garcia, S. Fan, and J. Carey, 2001. Sequence4: An integrated stratigraphic model for continental margins: *AGU Chapman Conference on the Formation of Sedimentary Strata on Continental Margins*, Ponce, Puerto Rico, June 17-19, 2001.

Swenson, J., C. Paola, L. Pratson, and B. Murray, 2001. A whole margin model: *AGU Chapman Conference on the Formation of Sedimentary Strata on Continental Margins*, Ponce, Puerto Rico, June 17-19, 2001.

Wolinsky, M.A., L.F. Pratson, and P. Haff, 2000, DEM slope histograms and evolution of mountain landscapes: *EOS Transactions American Geophysical Union,* v. 81(48), p. F624-625.

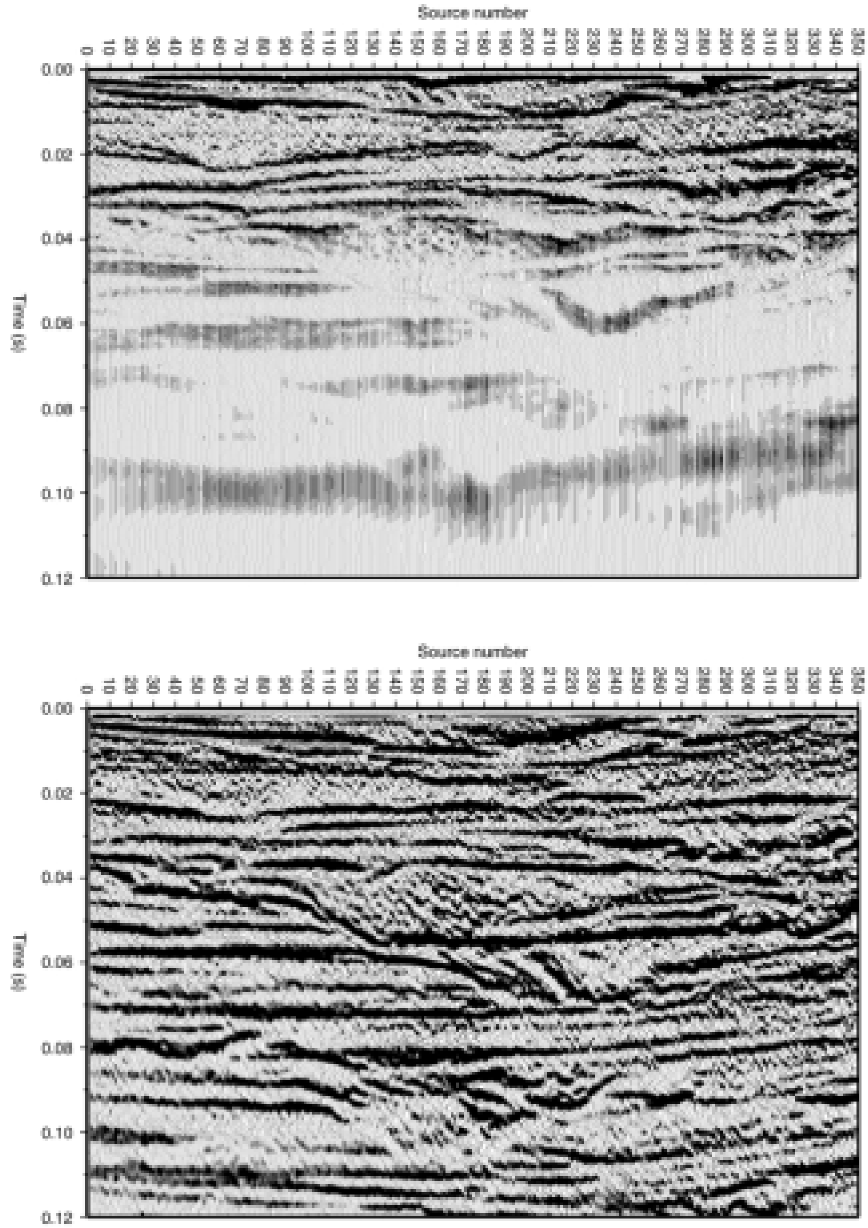

Figure 1. Synthetic seismograms of experimental strata containing buried channels: (top) strata are modeled as being predominantly sandy; (bottom) strata are modeled as being predominantly muddy. Note difference in attenuation.